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Biogenic particle flux and benthic remineralization in the Eastern Tropical South Pacific

W.M. Berelson [a,*], W.Z. Haskell II [a], M. Prokopenko [b], A.N. Knapp [c], D.E. Hammond [a], N. Rollins [a], D.G. Capone [d]

[a] Department of Earth Sciences, University of Southern California, Los Angeles, CA USA
[b] Geology Department, Pomona College, Pomona, CA, USA
[c] Earth, Ocean and Atmospheric Sciences, Florida State University, FL, USA
[d] Department of Biological Sciences, University of Southern California, Los Angeles, CA, USA

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ABSTRACT

We studied biogenic rain to the ocean interior and sea floor in the Eastern Tropical South Pacific (ETSP), a region at the intersection of three oceanic regimes; coastal upwelling, equatorial divergence and the South Pacific oligotrophic gyre. Sediment cores from ocean depths >4000 m were collected, pore water was expressed using both whole core squeezing and rhizon techniques, and profiles of nitrate and dissolved Si were modeled to estimate remineralization fluxes. Nitrate modeling was interpreted as representative of C_{org} remineralization assuming the oxic transformation of ammonium to nitrate. A broad range of TCO_2 fluxes were determined: 0.008–0.34 mmol C m^{-2} d^{-1}. The range in biogenic silica (bSi) remineralization flux was also large: 0.007–0.15 mmol Si m^{-2} d^{-1}. The pattern of TCO_2 flux showed higher particulate organic carbon (POC) inputs at sites closest to coastal and equatorial upwelling and lowest fluxes at the most oligotrophic site. Moored sediment traps, suspended at ~3700 m at 10°S, 100°W and 20°S, 100°W captured the annual pattern of mass and biogenic rain. The annual average mass flux was over five times greater at a 10°S site (30.8 mg m^{-2} d^{-1}) compared to a 20°S site (5.5 mg m^{-2} d^{-1}). The relative wt% of POC, PIC and bSi at these two stations were 4.9, 8.0, 15.5 and 6.6, 8.3, 2.7, respectively. The deep trap POC and bSi annual rain rates were within 0.5–4 times the benthic fluxes estimated from pore water models. The annual averaged surface ocean chlorophyll concentration estimated from satellites is a good predictor of POC rain to the ocean interior at the ETSP sites studied, as is ^{14}C primary production (PP). However, the POC rain into the deep ocean at ETSP sites per unit chlorophyll or per ^{14}C PP is significantly less than values obtained from the equatorial Pacific at 140°W or subtropical gyre station HOT. It appears that the ETSP, although underlain by an intense oxygen minimum zone, is inefficient at transferring C_{org} production to deeply sinking POC rain.

1. Introduction and background

One of the major goals of the JGOFS program in the 1980s and 1990s was to capture a robust picture of carbon transformations and fluxes within and through the water column (Murray et al., 1997). Studies in the Equatorial Pacific (EQPAC) extended the understanding of upper ocean carbon export to depth by including moored sediment traps, analyses of early sediment diagenesis, and patterns of sedimentation between 12°S and 10°N at 140°W (Rae et al., 1986; Honjo et al., 1995; Murray et al., 1996; Berelson et al., 1997). The JGOFS mission, in general, and the choice of EQPAC in particular, were guided by the importance of understanding the conversion of dissolved inorganic carbon to C_{org} and the export rates and pathways by which C_{org} leaves the upper ocean. Upwelling driven by divergence around the Equator, the relative importance of CO_2 degassing and production, and the importance of the tropics in light of global change, all contributed to make this study region a key target. Two long-duration time series stations in the oligotrophic northern sub-tropical gyres, BATS and HOT (Karl et al., 2001), similarly target carbon cycling. Because of the vast areal extent of these oceanic environments, mid-gyre biogeochemistry is also fundamental to understanding whole-ocean carbon systematics. Much less is known about biogenic budgets in the SE tropical Pacific and its oligotrophic gyre.

The work presented here describes biogenic export in low latitude, Eastern Tropical South Pacific (ETSP) waters that share similarities to both JGOFS-EQPAC and HOT sites. One goal of this study is to compare early diagenetic sedimentary reactions with the

* Correspondence to: Department of Earth Sciences 3651 Trousdale Pkwy University of Southern California Los Angeles, CA 90089. Tel.: +1 213 740 5828.
E-mail address: berelson@usc.edu (W.M. Berelson).

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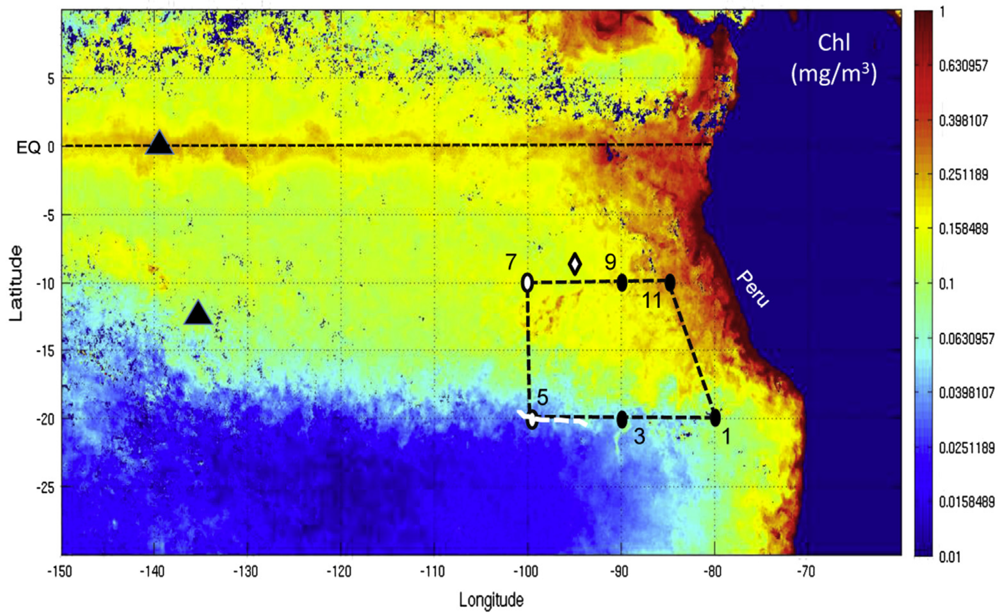

Fig. 1. Map of study area and stations 1, 3, 5, 7, 9, and 11. Map color correspond to MODIS chlorophyll concentrations and represent the 8-day average climatology during February, 2010. White diamond denotes location of NOAA buoy and the white dashed line denotes path of ARGO float deployed by U. Concepcion. Solid triangles denote position of EQPAC-JGOFS stations.

rain rates captured by deep, moored sediment traps. Upon assessing fluxes at depths >3500 m, we examine the relationship between deep particulate carbon rain rates and export from the upper ocean as determined by various methods; floating traps, Th-234 deficiency and O_2/Ar budgets (Haskell et al., 2013, Prokopenko pers. comm.). We also examine surface ocean state parameters (T, Chl) and primary production as they relate to deep-sea biogenic matter fluxes.

Our primary sites were located at 10° and 20°S at 100°W. The 10°S site is at a boundary influenced by both the NW trending Humboldt Current regime and the Equatorial upwelling regime. The 20°S site lies on the border of the oligotrophic S. Pacific Gyre yet is still subject to some seasonal forcing (Fig. 1). There are no known studies of pore water geochemistry from this study region (10–20°S, 85–100°W) and the nearest moored sediment traps to this location were deployments in the Panama Basin (5°N, 82°W) and at EQPAC. The coupling of pore water-based early diagenetic models of benthic fluxes to annual fluxes determined with sediment traps allows a check on the accuracy and coherency of 1-d mass balances (Berelson et al., 1997; Smith et al., 2013). In principle, deep-sea particle rain rates should be useful for extrapolation to surface ocean export and mixed layer primary productivity, if satisfactory models based on empirical data are developed. Here we merge several export flux estimates with several estimates of deep-sea rain rates and examine the pattern of POC flux with depth.

A mechanistic understanding of export forcing processes and particle settling velocity are goals of many particle flux studies (Emerson, 2013, Armstrong et al., 2002; Henson et al., 2012; Passow and De La Rocha, 2006). Also important is the export of POC deep into the ocean interior as this provides long-term sequestration of atmospheric CO_2. We focus on quantifying deep-sea biogenic fluxes, using both sediment traps and benthic diagenesis modeling, and comparing these to buoy records of sea surface temperature (SST) and satellite (MODIS) chlorophyll data. The relationship between POC flux and SST, Chl and primary productivity is viewed in the context of a similar relationship developed during JGOFS-EQPAC studies (Berelson et al., 1997) and at the Hawaiian Ocean Time series.

2. Study region

Two cruises took place in February–April 2010 and again in 2011 along transects that had primary stations along 10°S and 20°S, between 80°W and 100°W (Fig. 1). The sea floor in this region is classified as abyssal Peru Basin (>3500 m) and the sediments are predominantly brown muds (Lyle, 1992). The NE trending East Pacific Rise lies to the west of the study region at about 110°W. Sedimentation rates are <1 cm/kyr and the general distribution of biogenic sediments (opal and calcium carbonate) is dominated by equatorial processes with attenuation of these constituents scaling with distance from the equator (Lyle, 1992).

Surface currents in this region are dominated by the NW trajectory of the Humboldt and South Equatorial currents. Surface waters along the 10°S transect have nitrate concentrations generally >5 μM while waters in the western portion of the 20°S transect have nitrate near or below detection limits (<0.1 μM) for all year (Garcia et al., 2010). Deep waters that bathe the sediments are likely sourced from lower Antarctic Bottom Water (Rafter et al., 2013). The carbonate compensation depth in this region lies near 4000 m (Lyle, 1992).

The ETSP study region differs from the EQPAC and HOT regions in that the ETSP, especially the 10°S transect, bisects a strong oxygen minimum zone (OMZ). The intensity of the OMZ in the northern transect is illustrated by Jacquot et al. (2013), with values on the 2010 cruise <5 μM at its core ($\sim$400 m) at the nearshore stations 11 and 9 and <10 μM at station 7; oxygen concentrations were lower on the 2011 cruise due to La Nina conditions, <2 μM at the core of the OMZ at Sta. 11 (Prokopenko, unpublished data). The southern transect (20°S) also intersects the OMZ but oxygen deficiencies are not as extreme (<20 μM oxygen at Sta. 1 and <50 μM at Sta. 3). The OMZ thickens and intensifies to the east towards South America, yet persists to the west beyond 100 °W although not as far as EQPAC, 140°W.

3. Methodology

Sediment cores were obtained with a multi-coring device (Barnett et al., 1984) on the February–April 2011 cruise. This